8-2018

2018 Learning How to Think Like an Engineer: A Design-Based Research Study of Kid Spark Education's Curriculum in Kindergarten

Tessa Tinkler
The Nonprofit Institute, University of San Diego

Megan Kelly
The Nonprofit Institute, University of San Diego

Ida Rose Florez
The Nonprofit Institute, University of San Diego

Learning How to Think Like an Engineer: A Design-Based Research Study of Kid Spark Education's Curriculum in Kindergarten

August 2018

KIDSPARK EDUCATION

Presented by:
Caster Family Center for Nonprofit and Philanthropic Research

University of San Diego
SCHOOL OF LEADERSHIP AND EDUCATION SCIENCES
THE NONPROFIT INSTITUTE

About Kid Spark Education

The mission of Kid Spark Education is to help children (especially girls, children from low-income families, and minorities) prepare for a lifetime of learning about science and technology.

About The Nonprofit Institute's Caster Family Center for Nonprofit and Philanthropic Research

The Caster Center is housed within The Nonprofit Institute in the School of Leadership and Education Sciences at the University of San Diego. The mission of the Caster Center is to provide research, evaluation and consulting services that build the leadership and strategic and evaluative-thinking capacity of local nonprofits, as well as to be the leading source of information, data and research on the local nonprofit sector.

Project Team:

Tessa Tinkler, PhD
Senior Research Associate, NPI Caster Center

Aya Tore, MA
Research Assistant, NPI Caster Center

Meghan Kelly, MPA
Research Assistant, NPI Caster Center

Connelly Meschen, MArch
Administrative Coordinator, NPI Caster Center

Ida Rose Florez, PhD
CEO, Early Childhood System Solutions

Michael Lindsay, PhD
Adjunct Instructor, Department of Leadership Studies

Caster Family Center for Nonprofit and Philanthropic Research
The Nonprofit Institute
School of Leadership and Education Sciences
University of San Diego
www.sandiego.edu/npresearch

Cite As:

Tinkler, T., Kelly, M., Florez, I.R. (2018). *Learning How to Think Like an Engineer: A Design-Based Research Study of Kid Spark Education's Curriculum in Kindergarten*. San Diego, CA: The Nonprofit Institute, University of San Diego.

Acknowledgements:

The Nonprofit Institute's Caster Center would like to acknowledge the Chollas-Mead Elementary and Bayside Elementary teachers and administration, as well as Kid Spark Education's staff for their time and participation in the data collection process.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

> *"The students learned what engineers are; that there is a whole world of engineering out there; they won't be intimidated by it."*
>
> – Teacher

In January 2017, Kid Spark Education (Kid Spark), a nonprofit organization focused on creating engineering educational experiences for children, commissioned The Nonprofit Institute's Caster Family Center for Nonprofit and Philanthropic Research (NPI) at the University of San Diego to conduct a research study exploring the implementation of their early childhood curriculum (PreK-1) in public kindergarten classes. Kid Spark provides applied Science, Technology, Engineering, and Math (STEM) programs to elementary and middle schools and other youth-serving organizations. Each program consists of grade-level aligned curricula and Mobile STEM Labs that contain engineering materials such as construction blocks, wheels, and joints.

Previous studies examining the use of Kid Spark's curriculum in preschool settings found that adult mentors were an essential component in supporting young children through the curriculum. Given Kid Spark's interest in serving kindergarten and first grade classrooms where adult to student ratios are much larger than in a preschool setting, this study sought to identify the conditions necessary to implement the curriculum in an elementary school setting. This study was conducted in two phases between September 2017 and June 2018. In Phase 1, NPI researchers and teachers partnered through an iterative process to enhance the original curriculum, implement it in kindergarten classes, assess its strengths and weaknesses, and further refine the curriculum. In Phase 2, NPI researchers assessed the impact of the revised curriculum on student and teacher learning.

The analysis of data from teacher focus groups and interviews, classroom observations, and photographs of students' constructions provide evidence that implementing the revised curriculum impacted students' and teachers' development of a STEM identity. Students showed evidence of growth in building foundational STEM fluencies, engaging in science and engineering practices, and developing knowledge of the field of engineering. Teachers demonstrated increased self-efficacy and value for the teaching of engineering as well as increased knowledge in basic engineering concepts and practices.

Key Findings After Participating in Kid Spark's Revised Curriculum:

Students…	***Teachers…***
• Showed increased complexity and evidence of symmetry in their constructions. • Developed spatial reasoning skills • Progressed in their use of engineering practices such as hypothesis testing and problem solving. • Increased their understanding and use of STEM vocabulary.	• Increased their self-efficacy and value for teaching engineering to primary grade children. • Used STEM vocabulary and concepts with children through Kid Spark lessons. • Reported wanting to use the Kid Spark curriculum next year with their kindergarten students.

Key Recommendations for Future Curriculum Development:

- **Utilize the revised curriculum's format and content** to guide the final development of the PreK-1 curriculum. In further refinement of the units/lessons, prioritize instruction around the engineering concepts and then align building activities with the concepts.
- **Develop training and support materials for teachers** that include background information on engineering concepts and practical tips for using the blocks. Teachers preferred a handout for the content knowledge and a video or handout for the construction tips.
- **Make minor revisions to the Kid Spark Mobile STEM Labs** including re-designing figurines to represent greater gender and ethnic diversity, ensuring there are enough blocks for each child to complete a build from a construction mat, and updating construction mats with high resolution images and step-by-step visual instructions.

NPI commends Kid Spark for its commitment to learning and growth through its ongoing support of research and evaluation of its educational programs. This study was initially born out of Kid Spark's desire to better understand the impact of its programs on young children, and has resulted in both an enhanced curriculum and compelling evidence of its impact on young children and their educators.

OVERVIEW AND BACKGROUND

As technological innovation has dramatically shifted the global workforce, PreK-12 schools are increasingly recognizing the need to focus on developing students' knowledge and competencies in science, technology, engineering, and math (STEM). These efforts have opened up new opportunities for students to acquire 21st century skills such as problem solving, critical thinking, and creativity. Most STEM curricula have focused on older children, yet recent developmental research suggests that young children not only have the capacity to learn and think like scientists,[1] but their free play actually mimics design processes in engineering.[2] As young children play with materials, they employ pre-engineering thinking—making hypotheses, observing phenomena, and conducting and refining experiments.[3] Research suggests that engaging children early in STEM when they are naturally interested in exploring and understanding the natural and constructed world is critical to maintaining a pipeline of children who have the interests and competencies to excel in STEM fields.[4]

In January 2017, Kid Spark Education (Kid Spark), a nonprofit organization focused on creating engineering educational experiences for children, commissioned The Nonprofit Institute's Caster Family Center for Nonprofit and Philanthropic Research (NPI) at the University of San Diego to conduct a research study exploring the implementation of their early childhood curriculum in public kindergarten classes. Previous studies examining the use of Kid Spark's curriculum in preschool settings found that adult mentors were an essential component in supporting young children through the curriculum.[5] Given Kid Spark's interest in meeting the unique needs of kindergarten and first grade classrooms where adult to student ratios are much larger than in a preschool setting, this study sought to identify the conditions necessary to implement the curriculum in a public school setting.

This study was conducted in two phases between September 2017 and June 2018. In Phase 1, NPI researchers and teachers partnered through an iterative process to enhance the original curriculum, implement it in kindergarten classes, assess its strengths and weaknesses, and further refine the curriculum. In Phase 2, NPI researchers assessed the impact of the revised curriculum on student and teacher learning. The guiding research questions are listed on the following page.

---

[1] Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science, 337*(6102), 1623-1627.

[2] Bagiati, A. & Evangelou, D. (2016). Practicing engineering while building with blocks: Identifying engineering thinking. *European Early Childhood Education Research Journal, 24*(1), 67-85. | Bairaktarova, D. Evangelou, D. Bagiati, A. & Brophy, S. (2011). Designing environments to promote play-based science learning. *Children, Youth and Environments, 21*(2), 212-235.

[3] Brophy, S. & Evangelou, D. (2007). Precursors to engineering thinking (PET), *Proceedings of the Annual Conference of the American Society of Engineering Education*. Washington, DC: ASEE.

[4] Eshach, H. & Fried, M. N. (2005). Should Science be Taught in Early Childhood? *Journal of Science Education and Technology, 14*(3), 315-336.

[5] Vazquez, O., Guarassi, I. & Carr, R. (2012). *Designing Curriculum and Building Minds: Developing Readiness for Science-related Skills and Dispositions*. San Diego CA: Center for Academic and Social Advancement, University of California, San Diego.

Guiding Research Questions

Phase 1: What are the conditions necessary to implement Kid Spark in a public kindergarten class?

a. What type of scaffolding is needed to implement Kid Spark in kindergarten?
b. What should be included in the curriculum for teachers to use it with minimal preparation?
c. What should training/professional development look like?

Phase 2: How does the revised Kid Spark curriculum facilitate student learning of engineering foundational fluencies and practices and teacher learning of engineering concepts and pedagogy?

This report begins with a brief description of Kid Spark programs and a summary of the methodology used for Phases 1 and 2. Next, the findings are reported in two phases. Phase 1 reports on the lessons learned through the process of refining the curriculum to be used in kindergarten classes. Phase 2 reports on the revised curriculum's impact on students' and teachers' learning after it was implemented in kindergarten classrooms during spring 2018.

Description of Kid Spark

Kid Spark's vision is for children to see themselves as designers of their world and for educators to develop into being confident STEM mentors. Kid Spark provides applied STEM programs to elementary and middle schools and other youth-serving organizations. Currently, Kid Spark offers four grade-level-aligned curricula that progress in complexity and are designed to be flexible enough to stand alone or build upon one another. Accompanying the curricula are Mobile STEM Labs containing construction materials. For the PreK-5 students, each Mobile STEM Lab is designed to serve four students and contains materials such as varying sizes of blocks, wheels, joints, and mini figurines. A public classroom typically purchases eight Mobile STEM Labs to accommodate 25-30 students. The four curricula available to schools and organizations at the time of this report are listed below. The revision of the PreK-1 curriculum, Foundational Fluencies, is the focus of this study.

Kid Spark Pk-8 STEM Programs	Grade Level
Foundational Fluencies Educators mentor students to develop foundational capacities prerequisite to all STEM learning, like spatial reasoning, problem solving, and symbolization.	**PreK-1**
STEM Fundamentals Students begin to develop STEM Identity & Technology Fluency while exploring applied mathematics, mechanical engineering, and robotics.	2-5
Applications in Design and Engineering Students explore challenging STEM concepts from their everyday world, authoring with technology to solve problems and create new solutions.	6-8
Systems of Technology Students learn to use multiple technologies to create system solutions. Explorations include: mechanical and structural engineering, computer aided design & 3D printing, programmable robotics, and integrated design challenges.	6-8

METHODOLOGY

The findings presented in this report are based on a comprehensive synthesis of multiple data sources collected between October 2017 and June 2018 in kindergarten classes at Chollas-Mead Elementary and Bayside Elementary in San Diego, California. Both schools shared similar demographics. According to the school profiles in 2016/2017, more than three-quarters of children came from low income families, eight out of ten were Hispanic-Latino, and roughly one-half of students were English language learners.[6]

Phase 1 Methods: Curriculum Development

NPI researchers employed a design-based research approach[7] to revise Kid Spark's early childhood curriculum. Design-based research is a practice-oriented approach in which educational interventions are designed and tested in real educational contexts. Between October 2017 and June 2018, the following data sources were used to gather ongoing feedback from teachers in order to design a curriculum that could be used in any public kindergarten or first grade class setting (see Appendix A for methods of analysis).

Table 1: Phase 1 Data Sources

Data Source	Participants	Description
Teacher Focus Group #1	n=5	In October 2017, NPI researchers conducted a focus group with five kindergarten teachers at Chollas-Mead to gather initial feedback about their impressions of the original Kid Spark curriculum, including strengths and areas for improvement.
Teacher Focus Group #2	n=5	In November 2017, NPI researchers conducted a second focus group with the same five kindergarten teachers to share revised curriculum and gather additional feedback on areas for improvement.
Curriculum Feedback Forms	n=5	During the spring of 2018, the five participating kindergarten teachers were asked to provide written feedback on the strengths and challenges of each of the lessons after implementing them in their classrooms. This feedback allowed NPI researchers to revise curriculum as it was being developed.
Teacher Focus Group #3/ Interview	n=6	In June 2018, NPI researchers conducted a third focus group and a telephone interview with one teacher from Bayside who had implemented the revised curriculum with her kindergarten class during an eight-week rotation. The focus group and interview were designed to gather feedback on the strengths and challenges of the curriculum, as well as overall impressions of Kid Spark.

[6] See School Profiles at http://www.ed-data.org/

[7] Anderson, T. & Shattuck, J. (2012). Design-based research: A decade of progress in educational research? *Educational Researcher, 41*(1), 16-25.

Phase 2 Methods: Kid Spark Impact on Learning

From January through June 2018, the following data sources were used by NPI researchers to assess the impact of Kid Spark's revised curriculum on students' and teachers' learning (see Appendix A for methods of analysis).

Table 2: Phase 2 Data Sources

Data Source	Participants	Description
Focused Classroom Observations	n=7 observations • 1 classroom • 26 kinder students (4 focus students)	From January 2018 through June 2018, NPI researchers conducted 7 classroom observations in a single classroom as teachers and students participated in structured Kid Spark lessons. The observations captured whole class activities and focused on a table of four students (two female and two male). One researcher used a rubric to code the observations for students' development of STEM fluencies and engineering practices and another researcher wrote ethnographic fieldnotes (see Appendix B for coding rubric).
Pre/Post Free Build Classroom Observations	n=10 observations • 5 classrooms • 128 kindergarten students	In January/February and again in May/June 2018, NPI researchers observed five classrooms as students participated in their first and last free build lessons (i.e., a lesson in which students could use the construction toys to build whatever they wanted). One researcher used a rubric to code the observations for students' development of STEM fluencies and engineering practices and one researcher wrote ethnographic fieldnotes (see Appendix B for coding rubric).
Photos of Kid Spark Constructions	n=56 matched pre/post photos • 112 photos • 5 classrooms	NPI researchers analyzed photos comparing students' first free build in January/February 2018 to their final free build in May/June 2018. Students who worked collaboratively on their free builds were excluded from the photo analysis. Photos were scored based on the construction's complexity, evidence of patterns, and elements of symmetry (see Appendix C for photo coding rubric).
Pre/Post Engineering Self-Efficacy Teacher Survey	n=5 teachers • 1 school • 10 surveys • 5 classrooms	In October 2018, NPI researchers sent an online 40-question pre-survey to five teachers asking them about their self-efficacy in teaching engineering, perceived value for teaching engineering, and demographics. In June 2018, teachers completed a post-survey asking the same questions. NPI researchers adapted the survey from the Science Teaching Self-Efficacy Belief Instrument.[8]
Teacher Focus Group/ Interview	n=6 teachers	In June 2018, NPI researchers conducted a focus group with Chollas-Mead teachers and a telephone interview with a Bayside teacher to gather information on teachers' perceptions of Kid Spark's impact on student and teacher learning.

[8] Riggs, I., & Knochs, L. (1990). Towards the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74*, 625-637.

PHASE 1: CURRICULUM DEVELOPMENT

NPI researchers revised Kid Spark's PreK-1 curriculum in order to make it more suitable for a public kindergarten class. The research team designed a process that would allow children and teachers' experiences with the revised curriculum to inform the kindergarten curriculum design. As each unit was implemented, information from classroom observations and teacher feedback were used by the research team to modify future units. Information gathered through this iterative process affected changes such as the length of lessons, the amount of pedagogical support provided to teachers, and the content of teaching aids (e.g., vocabulary lists).

The revised curriculum was informed by literature in early childhood science and math instruction, especially research on the relationship of spatial reasoning skills to long-term achievement[9], and developmental math progressions. To the degree possible, lessons were created to align with Next Generation Science Standards (NGSS). Lessons align primarily with NGSS science and engineering practices and crosscutting concepts because there are limited NGSS disciplinary core ideas and performance expectations at the kindergarten level.

Both the original and revised curriculum contained the same construction materials (i.e., blocks) but in the revised curriculum, the construction mats (i.e., step-by-step building instructions) included constructions that were easier for small hands to assemble. The NPI research team, in collaboration with kindergarten teacher participants, revised the original curriculum to include the following elements listed in Table 3 (see Appendix D for the full revised curriculum).

Table 3: PreK-1 Original vs. Revised Curriculum

Original Pre K-1 Curriculum	Revised PreK-1 Curriculum
• Instructors Guide that includes: o Teacher Tips o Visual list of materials o Information on how Kid Spark builds STEM fluencies • 10 Construction Mats	• A 16-lesson sequenced curriculum with four themed units that progress in difficulty • Culminating free build lesson at the end of each unit for students to practice their skills • Unit alignment to Next Generation Science Standards (NGSS) and Common Core Math standards • Student learning objectives, vocabulary lists, recommended children's literature, and classroom organizational tips for each unit • Scripted language for teachers to follow for each lesson that includes engineering vocabulary and activities to explore concepts • Supplemental learning extensions

[9] Wai, J., Lubinski, D., & Benbow, C.P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance, *Journal of Educational Psychology, 101*(4), 817-835. Zhang, X. (2016). Linking language, visual-spatial, and executive function skills to number competence in very young Chinese children. *Early Childhood Research Quarterly, 36*, 178-189.

Key Takeaways from Curriculum Development

Through the process of developing, refining, and implementing the curriculum, NPI researchers identified strengths and challenges around training and support, the Kid Spark construction system, and curriculum design. These lessons learned can inform the final version of the PreK-1 curriculum, as well as all Kid Spark curriculum development.

Training and Support

Teachers felt the revised curriculum's sequenced and scripted format enabled them to implement the lessons with minimal support. Teachers participated in a Kid Spark-led in-person training before the curriculum revision process began and felt they benefitted from the introductory lesson. However, they also felt that with additional written and video support materials, they could implement the curriculum without in-person training. Teachers identified the following additional needs:

Additional Support Needs

- **More content knowledge on engineering concepts**: Teachers expressed a lack of confidence in their ability to teach concepts such as gravity, motion, reinforcements, etc. They suggested including background information with simple explanations for the concepts covered in each unit. Teachers referenced another STEM curriculum they had used in the past (FOSS Kits) as providing exemplary content knowledge to teachers.
- **Tips and tricks on using the blocks**: Some of the curriculum revisions NPI researchers made included tips on how to connect and disconnect blocks. Teachers felt these tips were extremely helpful and suggested a handout or video with practical tips on how to support students in using the blocks. Included in this would be an explanation of the functions of each of the blocks in the Mobile STEM Lab.

Kid Spark Mobile STEM Labs

The revisions to the original curriculum impacted the way teachers used the Kid Spark engineering materials and as such teacher feedback and research observations suggested the following areas for improvement:

Areas for Improvement

- **Organization of the Mobile STEM Labs not aligned with the revised curriculum**: In the original curriculum, each table of four students had access to a Mobile Stem Lab, complete with all blocks. The revised curriculum introduced each of the blocks gradually in order for students to develop competency using the blocks before advancing to more difficult builds. In this way, the curriculum was scaffolded without needing the one-on-one mentorship required with the original curriculum. In order to manage the classroom and scaffold the lessons appropriately, teachers felt they needed to organize the blocks by type and only give students access to the blocks necessary for each lesson. This could potentially make it difficult for different grade-levels to share the Mobile STEM Labs.
- **Uncertainty of each block's function**: Many blocks were included in the Mobile STEM lab but there was no information on their function. Teachers would like to be able to explain the function of each block.

- **Lack of blocks**: There were not enough blocks for every student to independently complete some of the builds. This was the case for the *Unit 3, Lesson 2 – Long Haul*, *Unit 4, Lesson 1 – The Caterpillar in Imagination Land*, and *Unit 4, Lesson 4 – The Helicopter*. Even for those lessons in which each child could build their own model, there were no extra pieces in case a block broke or was lost.
- **Fingers got stuck in blocks**: Little fingers got stuck in the blocks multiple times. Students had to use soap and water to slip their fingers out of the openings.
- **Broken blocks**: Over the course of the 16-week session 5 blocks were broken.
- **Construction mats difficult to follow**: The pictures on the construction mats were poor quality and it was very difficult to discern the direction of some of the blocks. Also, some of the steps were combined and the arrows which were intended to help clarify actually confused students and teachers.
- **Figurines not representative of the diversity of public school students**: Each Mobile STEM Lab included mini figurines that are intended to look like engineers, and the figurines all appeared to have white skin. Children immediately gravitated to the figurines because it allowed their constructions to become back drops for their play. Given their critical importance to the students' experience, and Kid Spark's mission to make engineering accessible to underrepresented groups, it is important the figurines model the ethnic and gender diversity of public school children.

Kid Spark Curriculum Design

The revised curriculum allowed kindergarten teachers with little to no adult support in the classroom to implement it to a classroom full of children, many of whom were in transitional kindergarten, spoke limited English, or had a special education designation.

Main Findings for the Ongoing Refinement of the Curriculum

- **Collaboration both a strength and a challenge**: Developmentally, young children do not share well when their own self-interest is at stake.[10] Consistent with this, students struggled to collaborate when they were supposed to build a model together because there were not enough blocks for them to build their own. However, when students participated in a free build or when the lesson contained a particularly difficult model, they often elected to collaborate. Building collaboration into the lessons allowed students to practice an important skill, yet collaboration worked best when it was mutually beneficial to both/all students.
- **Teachers utilized as resources**: At Chollas-Mead, the entire kindergarten team implemented Kid Spark in their classrooms. This allowed them to share resources (e.g., one teacher made vocabulary cards and all teachers used this resource) and plan more effectively. Teachers reported discussing the lessons during their team planning and agreed that working as a team made the lessons successful.
- **Teachers' heavy reliance on the scripted language in the revised curriculum**: Teachers had very little prep time and often seemed to be reading the lesson instructions for the first time with students. Teachers reported that having the script allowed them to facilitate the lesson with minimal preparation.

---

[10] Smith, C.E., Blake, P.R. & Harris, P.L. (2013). I Should but I won't: Why young children endorse norms of fair sharing but do not follow them. *PLoS ONE* 8(3): e59510. https://doi.org/10.1371/journal.pone.0059510

- **40+ minutes needed for more difficult lessons:** In the early lessons, students were introduced to one block at a time and a 20-25 minute block of time was adequate. However, for Units 2-4 teachers needed more time to complete a lesson. At Bayside, where the teacher had three 25-minute blocks of time per week, the teacher either took two sessions to complete one lesson or repeated the lesson two times in one week to ensure students could complete it.
- **Implementation of the curriculum unique for each teacher**: Some teachers shifted between small and large group instruction throughout a lesson whereas others had students in their small groups during all lessons. While the management of students is likely best left up to teachers, it seemed that certain difficult steps or skills were best explained in a large group where the teacher could demonstrate how to accomplish a given task to the whole class at one time.
- **"Free Builds" well-liked and afforded children opportunities to be creative, problem-solve, and collaborate**: Each unit concluded with a free build in which students had access to all materials and could build as they wish. Teachers reported that students enjoyed these sessions and whenever there were any gaps in time during the other lessons, students would initiate their own free build.
- **Opportunities to refine units/lessons:** There was limited time to fully develop the curriculum so that each unit had a clear organizing theme. Having cohesive themes will ultimately strengthen the curriculum's alignment with science and math standards.

Overall, teachers were very enthusiastic about their experience implementing the curriculum and felt it served as an excellent introduction to engineering for both themselves and their students.

PHASE 2: KID SPARK IMPACT ON LEARNING

Impact on Student Learning

Through participation in the revised Kid Spark curriculum, students were introduced to and given the opportunity to practice many of the cross-cutting concepts and science and engineering practices that make up the K-12 Science Education Framework,[11] the guiding framework for the science standards adopted in more than two-thirds of the United States.[12] Based on an analysis of classroom observation data, scoring of students' free builds at the beginning and end of the curriculum, and teacher feedback, the revised curriculum supported students' development of foundational STEM fluencies, afforded opportunities to use engineering practices, promoted social-emotional development, and introduced students to the field of engineering.

Developing Foundational STEM Fluencies

Data analysis suggests that as students progressed through the 16-week curriculum, they exhibited increased complexity in their building and improved spatial awareness. The curriculum also provided students opportunities to practice the NGSS cross-cutting concepts of patterns; scale, proportion, and quantity; and structure and function.

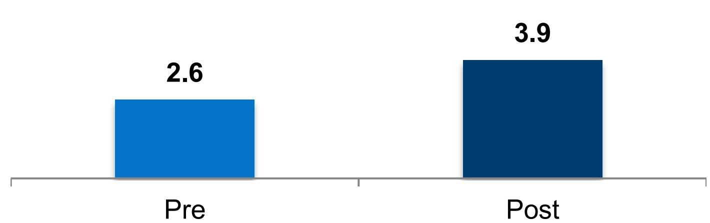
Evidence from Pre/Post Free Builds

Complexity and symmetry increased after participating in Kid Spark curriculum

Evidence of student growth in the development of foundational fluencies comes from an analysis of students' first (pre) and last (post) free builds. Students' free builds were photographed and scored based on a rubric that coded each construction's complexity, pattern-making, and symmetry (see Appendix C). Each element of the rubric was summed to create a total score for each of the pre and post constructions. As Figure 1 shows, students' total scores significantly increased from pre to post. Students' constructions demonstrated increased complexity and symmetry after participating in the Kid Spark curriculum. Making patterns did not change, however this is likely because each block type has a different function; thus, making easily recognizable patterns based on color or shape would not necessarily coincide with more complex uses of the blocks.

Figure 1: Average Pre and Post Free Build Score (n=56)*

(Scores could range from 0 to 6.5)



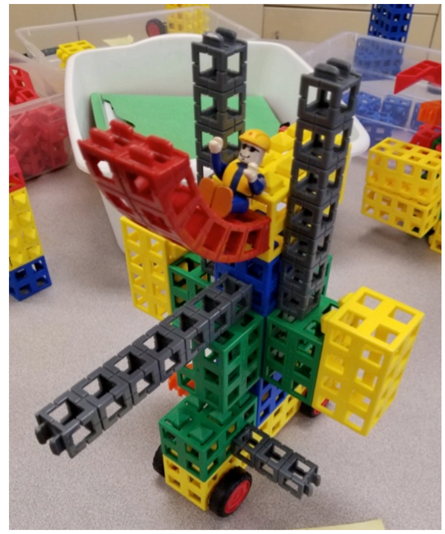
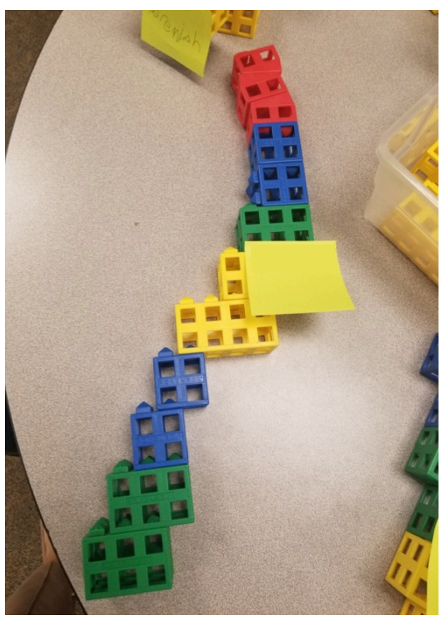
** Statistically significant difference (p<.05)*

[11] National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards*. Washington, DC: The National Academies Press.

[12] The Next Generation Science Standards (NGSS) have been adopted in 19 states and 19 other states have developed their own standards, all of which are based on the K-12 Framework for Science Education. For more information, see http://ngss.nsta.org/About.aspx.

Figure 2 exemplifies the growth in the complexity of students' constructions over time and demonstrates how students used symmetry, progressed from designing mostly 2-dimensional structures to 3-dimensional structures with internal space, and built increasingly functional constructions with structural integrity that resembled actual objects. Additionally, the revised curriculum allowed students to explore the relationships between structure and function, one of the cross-cutting concepts in the K-12 Science Education Framework.

Figure 2: Side-by-Side Comparisons of Students' First and Last Free Builds

	First Free Build	Last Free Build
Student 1 Final construction shows improved symmetry and is 3-dimensional		
Student 2 Final construction shows structural integrity and a visible function		

Spatial Awareness

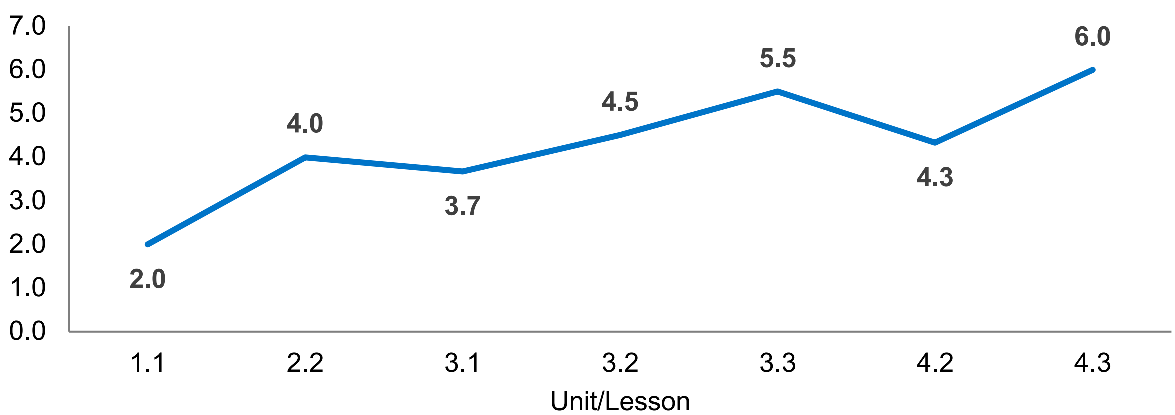
> *"They [developed] the skills that [have] to do with putting things together, spatial relationships."*
> – Teacher

Spatial reasoning refers to the set of skills involved in being able to mentally picture and physically manipulate objects. Spatial skills include being able to think about how objects look when rotated, how objects look from different perspectives, how parts of an object fit together, and how to construct a 3-dimensional object from a 2-dimensional model. Developing spatial awareness in early childhood is critical to the development of students' mathematical skills,[13] and research suggests that the ability to reason spatially is a strong predictor of achievement in STEM disciplines.[14] During the Kid Spark lessons, students demonstrated increased evidence of <u>mental rotation</u>, recognizing and using <u>symmetry</u>, and <u>building a 3-dimensional object from a 2-dimensional model</u>.

> **Students Demonstrated Increase in:**
> Mental Rotation
> Using Symmetry
> 2D model ➡ 3D object

One table of four students were observed during seven of the structured lessons (vs. free builds) to assess what and how they learned by participating in the revised curriculum. In order to assess students' spatial reasoning skills, observers coded every time students demonstrated mental rotation or symmetry. For each opportunity a student had to demonstrate one of these skills, the observer coded how clear the evidence was that the student successfully demonstrated the skill (0=no evidence to 2=clear evidence). Each lesson was also given a complexity score to account for the difficulty of the lesson (see Appendix B for rubric and complexity scores for each lesson), and the complexity score was then added to each student's highest daily symmetry and mental rotation score. As Figure 3 shows, while there were spikes and dips, on average, students increased their spatial reasoning skills from the first to the last lesson.[15]

Figure 3: Average Student Score of Spatial Reasoning Across Lessons (n=4) *(Possible student scores ranged from 0-6.5)*



13 Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development, 15(1),2-11.*

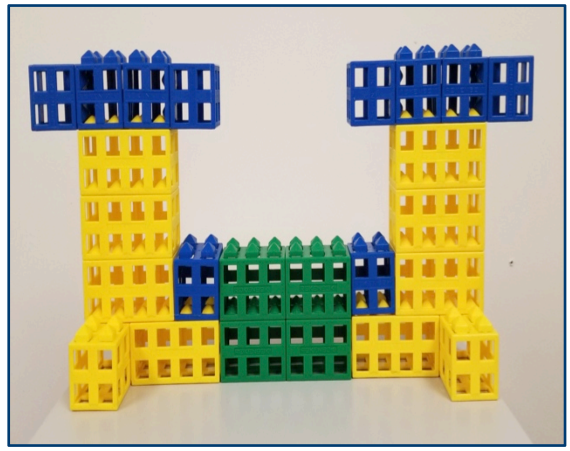
14 Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*, 817–835.

15 Without the addition of the lesson complexity scores, students increased their mental rotation and symmetry scores from the first to the last lesson.

Symmetry in Action

Many of the structured lessons required students to use symmetry to successfully construct their model. One such example was in *Unit 3, Lesson 3 – Make Your Castle Strong*, in which students built a castle wall. The students were organized into pairs and each student was responsible for building one half of the castle wall. This lesson required students to build symmetrically in order to properly connect the two halves of the wall.

Field Note Excerpt



> *The teacher tells students the two halves will be symmetrical and asks if kids remember the word symmetrical.*

SEVERAL KIDS: Yes.

> *Teacher is demonstrating how to build Part 1 piece-by-piece.*

TEACHER *(to kids)*: See what I did?

> *Boy points out that the blue blocks on top are symmetrical.*
>
> *The kids go to their tables and Student 1 (S1) and Student 2 (S2) are building together.*

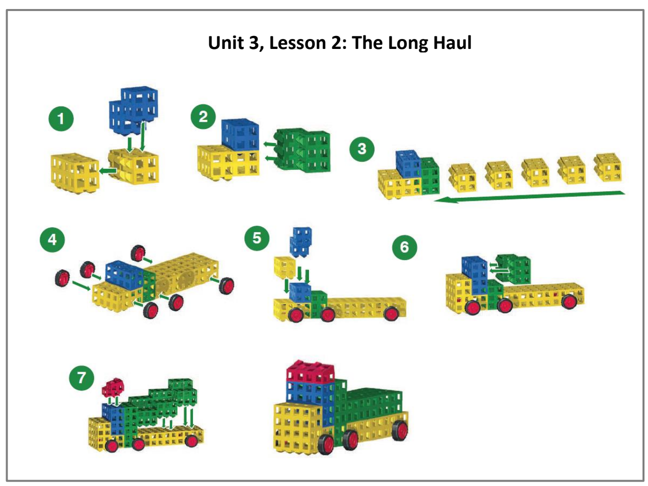
S2: I do it! I do it!

> *(S1 & S2 finish first half of castle and start building Part 2 together).*

S1: I can help you. It's ok, it just has to be like the same.

> *(S1 is showing S2 how to fix yellow blocks and connecting the blue blocks on top.)*

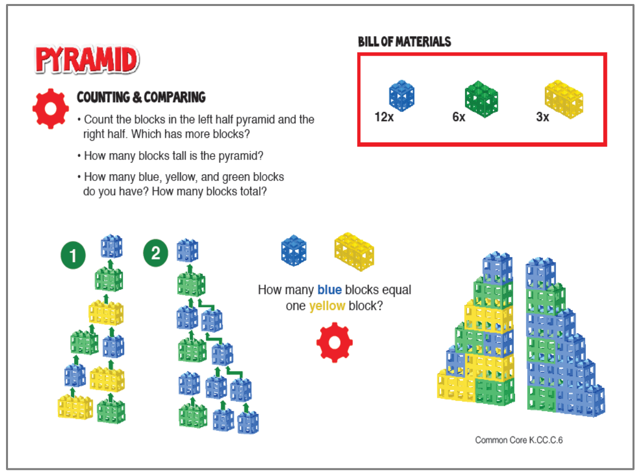
Sequencing



Sequencing is a fundamental planning skill in kindergarten covered in both language arts (e.g., logical order of storytelling) and math (e.g., ordering numbers). In seven of the lessons, students were required to use sequenced construction mats to build 3-dimensional objects. The coded data on the four focal students did not show clear evidence of growth in sequencing across lessons because two students successfully followed the sequence on the construction mats from the very first lesson and two of the students were unable to follow the sequence correctly on any of the lessons. However, the field note data showed many instances of students practicing sequencing and then problem solving when they did not correctly follow the sequence. Additionally, the students became competent at using the sequenced construction mats and during the final free build, some students chose to build with the construction mats instead of building their own constructions.

Pattern-Making

Identifying and making patterns is both a foundational mathematical skill and a cross-cutting concept in the K-12 Science Education Framework. Early lessons in the revised curriculum lent themselves best to pattern identification and pattern-making. In particular in *Unit 2 Lesson 2 – Patterns and Pyramids*, students used blocks to make repeating patterns and then collaborated to build a pyramid that contained patterns in the block type. Teachers had students practice making patterns, build the pyramid, and then discuss the use of patterns in the pyramid. The following field note excerpt describes the beginning of the lesson, in which one of the teachers introduced the concept of patterns.



Field Note Excerpt

TEACHER: Today we're going to talk about patterns *(she grabs yellow, blue, & green blocks)*. I made a blue, green & yellow pattern. Can I do it again?

> *Teacher used a chair up front to line blocks up next to each other – 6 blocks in a pattern of blue, green, yellow. Teacher asks one boy to share with the class what he just said.*

BOY: They are small, medium, and big.

TEACHER: That is another pattern.

> *She has all kids say the new pattern out loud three times.*
>
> *Teachers ask kids how many pyramids are on each block – kids shout out different answers. Teacher has kids say "4, 6, 8" as a pattern out loud three times.*

TEACHER (*looking at paper*): Could we make a different pattern with these blocks?

KIDS: Yes!

> *The students go to their tables and practice making their own patterns. Then they come back together at the front of the room.*

TEACHER (*asks a kid*): Can you tell me what the pattern is?

BOY: Blue, yellow, green.

TEACHER: Did he do it over again?

KIDS: Yes.

Developing Engineering Practices

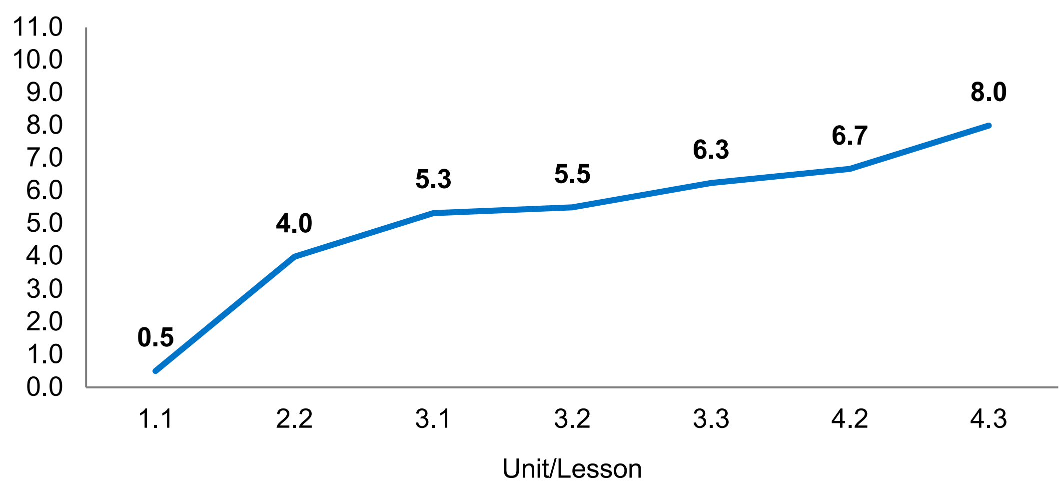
Studies of young children's play have identified ways in which their play imitates engineering practices. Based on NGSS Kindergarten Engineering Design Standards[16] and the K-12 Science Education Framework, observers coded classroom observations for the following engineering practices: gathering information, explaining how things work, problem solving, and hypothesis testing. Students progressed in their engineering thinking throughout the lessons.

> *"I think they learned problem solving. Whenever they would build they would find ways to make it better. Instead of getting mad, they liked making it better."*
> – Teacher

As students progressed through Kid Spark lessons, there was more evidence of their engineering thinking

Using the same methodology as was used to assess students' development of spatial reasoning, for each opportunity a student had to demonstrate one of these skills, the observer coded how clear the evidence was that the student successfully demonstrated the skill (0=no evidence to 2=clear evidence). Each lesson was also given a complexity score based on how difficult the lesson was to accomplish, and the complexity score was then added to each student's highest combined "engineering practices" score for each lesson in order to compare changes over time (see Appendix B for rubric and complexity scores for each lesson). As Figure 4 shows, students showed more evidence of engineering thinking as they progressed through the lessons.[17]

Figure 4: Average Student Scores of Engineering Practices Across Lessons (n=4)
(Possible student scores ranged from 0-10.5)



[16] California Department of Education. NGSS Kindergarten Disciplinary Core Ideas Standards. https://www.cde.ca.gov/pd/ca/sc/ngssstandards.asp

[17] Without the addition of the lesson complexity scores, students progressed in employing engineering practices from the first to the last lesson.

Explaining How Things Work

There were many instances of students explaining what their construction was and what it was designed to do. In *Unit 4, Lesson 3 – Helicopter*, the teacher prompted students to explain how the helicopter flew.

Fieldnote Excerpt

Teacher holds a helicopter up in front of the kids.

TEACHER: Does this have wheels?

KIDS: No.

TEACHER: How is it going to move without wheels?

BOY 1: By flying.

TEACHER: How?

BOY 1: With the wind.

GIRL 1: It's gonna move when people drive it.

GIRL 2: They have things in the back. *(referring to the rotor)*

TEACHER: What do they *[the rotor]* do?

KID: Spin.

TEACHER: That is called a rotor.

Teacher demonstrates a completed helicopter. Kids then go to their tables and build a helicopter. After they are done, they all gather at the front of the room.

TEACHER: The helicopter will fly through the air and gravity won't pull it down. What keeps it from pulling it down?

BOY 1: Engine.

TEACHER: Think about what you just added to your helicopter.

Girl holds the helicopter and starts pointing to all the pieces that were just added to make the rotor.

TEACHER: What are they called?

SOME KIDS *(mumbling quietly, sounds like):* Motors.

Teacher says rotors and has kids repeat

In this field note, the classroom discussed how helicopters work but the teacher did not accurately explain how a rotor keeps the helicopter in flight even with the force of gravity. This particular teacher commented during the focus group that she wished she had more knowledge to explain the science and engineering concepts they covered in the lessons. This is one area for improvement in the revised curriculum.

Problem Solving

Students demonstrated many instances of problem solving, sometimes with their teacher's assistance, other times with the help of a peer, and sometimes unassisted. Interestingly, instances of problem solving occurred most frequently during students' free building.

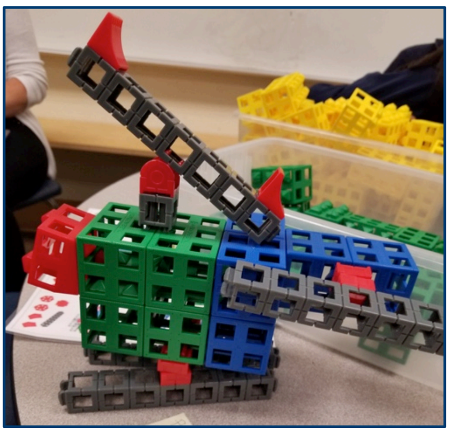
Fieldnote Excerpts from Free Builds

Student 4 adds one yellow to the bottom of his tower and tries to stand it up.

It doesn't stand (it is unbalanced and too heavy on one side).

He flips it over and it stands.

Problem solving occurred most frequently during free builds



Student 3 (S3) attaches one leg to bottom middle of helicopter.

S3 tries to stand up helicopter on table and it falls over.

She picks it up and tries to attach another leg right next to the first one.

Helicopter stands up (though legs are not in correct position).

Hypothesis Testing

A few of the lessons were intentionally designed to encourage students to test the functionality of their constructions and experiment to make them stronger. One example of this was *Unit 3, Lesson 1 – How Much Load Can it Hold?* in which students built bridges, tested their integrity, and then reinforced the bridge to withstand increased weight.

Fieldnote Excerpt from Bridge Lesson

Student 3 (S3) is mostly watching.

Student 4 (S4) adds yellow blocks on either side of blue blocks. S4 adds five blue blocks - four are under yellow (looks symmetrical) and one in middle of original blue bridge.

S4 puts it on his chair and tries to sit on it.

S4: It doesn't break! Powerful, powerful.

S3 is just watching and occasionally says "no" to S4.

Developing Social Skills

Kindergarten is as much a time for academic preparation as it is for social-emotional learning, and young children learn primarily through play. Kid Spark's emphasis on play afforded students many opportunities to learn to work together and, according to teachers, it engaged students with special needs in critical ways. For example, teachers reported that some of their students who typically presented behavioral challenges remained engaged during Kid Spark activities. Likewise, teachers felt students' communication skills improved which is essential for English Language learner students who benefit from talking with their peers and teachers in English.

According to teachers, emphasis on play helped keep special needs students engaged

> *"[My students] grew. Looking at free builds we did – in the last one a lot of them worked together…whereas before it was more 'this is mine' – Their social skills and their communication skills grew because they were having to talk to each other."*
>
> – Teacher

The revised curriculum embedded many opportunities for children to collaborate, and observations revealed instances in which children became mentors, asked each other for help, and worked together through difficult tasks. There were also just as many instances where students fought with each other or a less capable student gave up and disengaged while the more capable child completed the task independently.

An Instance of Successful Collaboration

Two of the focal students (two girls) were paired together throughout the 16-week curriculum implementation. One of the students, "S1", was a very capable child who was able to successfully complete most of the Rok Bloc tasks and served as a mentor for her partner, "S2". S2 had a special education designation and struggled to correctly follow the construction mats. Although she showed evidence of mentally rotating objects and building 3-dimensional structures, she was only able to produce an exact replica of the builds with support from S1. Their partnership served them both because S1 was able to be a peer mentor and S2 was able to accomplish tasks she would not have been able to do on her own.

Field Note Excerpt of Two Children Building a Truck using a Construction Mat:

S2 starts connecting yellow blocks to each other, S1 stops her and says she thinks they go "back here" (pointing to other end), S2 agrees and pulls them off.

Girls are struggling to get yellow blocks connected.

S1 *(attaching 1 yellow)*: Like that.

S2 *(adding more yellow blocks – five total)*: Gimme wheels.

S1 counts the wheels on the instruction sheet (counts to six)

S2 starts to put on a wheel and S1 says wait and shows her that the blocks are starting to disconnect.

S1 pushes them back together.

S2 starts attaching wheels (not in the correct spots).

Instances of Challenges with Collaboration

The other two focal students (two boys) were also paired together throughout the curriculum, yet they struggled to work together. Similar to the other partnership group, S4 was a strong builder and could successfully follow the construction mats whereas S3 was not as strong of a builder and was often frustrated. Although there were instances in which S4 mentored S3, there were many times he would take over and complete a build independently.

Field Note Excerpt of Two Children Building a Bridge:

S3 is just watching and occasionally says "no" to S4.

Around the room kids are adding more blocks and trying to stand on structures.

S4: We made it.

S3 *(looks upset)*: I didn't make it!

For young children, curriculum should foster opportunities for students to independently create while also encouraging collaboration

These struggles with collaboration highlight the need for teachers to carefully plan groupings and reassess throughout the curriculum implementation to ensure all students are given opportunities to build their skills. Navigating challenges around sharing and working together is not new terrain for kindergarten teachers, but it is essential that the curriculum fosters developmentally appropriate opportunities for collaboration in which students can learn to work together while also being able to build independently.

Learning about the Field of Engineering

What is an Engineer?

One of Kid Spark's primary goals is to inspire children to see themselves as engineers in hopes of ultimately increasing the number of students seeking engineering careers. In light of this vision, the curriculum was revised to include descriptions of the various types of engineers and what engineers do. Students demonstrated their understanding of engineering through class discussions about the work of engineers. The following field note excerpts illustrate students' expanded understanding of the field of engineering.

> *"The students learned what engineers are; that there is a whole world of engineering out there; they won't be intimidated by it."*
>
> – Teacher

Field Note Excerpts from Class Discussions

Teacher reminds the students that last time they were in the room they talked about what engineers do and asks if anyone remembers.

A FEW KIDS *(yell out)*: They build things.

TEACHER: Why?

BOY: To solve problems.

Students demonstrated their understanding of engineering through class discussions about the work of engineers

In a previous lesson, students were instructed to become various types of engineers and build for an Imaginary Land. They learned about automotive engineers, marine engineers, and toy engineers.

TEACHER: We've learned about engineers – what do we call the ones who build cars?

BOY: Automotive engineers.

TEACHER: The kind who build ships & boats?

(kids do not seem to know, Teacher finally tells them - marine engineers)

TEACHER: Today we're going to be aircraft engineers – what do they build?

BOY: Airplanes?

Teachers reported that their students now knew what engineers were and one teacher said some of her students called themselves engineers as they were constructing with the Rok Blocs. Another example came during the final focus group interview. A teacher shared an example of how she was able to relate their Kid Spark lessons to a real-world application.

> *"One example was we went to the zoo.*
> *I was all excited because they had a bridge that went straight across.*
> *We didn't get to go on it but we brought that back [Kid Spark bridge lesson].*
> *'What was that (pointing to the beams)? What made it stay that way?'*
> *So that was pretty cool."*
>
> *– Teacher*

STEM Vocabulary Development

The revised curriculum includes relevant vocabulary for each unit. Some of the vocabulary is related to math learning (e.g., size comparisons, shapes, etc.) and other vocabulary is related to science and engineering (e.g., physics concepts, engineering terms, etc.). Field notes from the observations demonstrated many instances where students used the vocabulary in conversation. Most often students used the vocabulary in conversations with their teachers but there were some instances where students used the vocabulary when talking with each other. Table 4 shows evidence of students' vocabulary use.

Table 4: Evidence of Students' Vocabulary Use

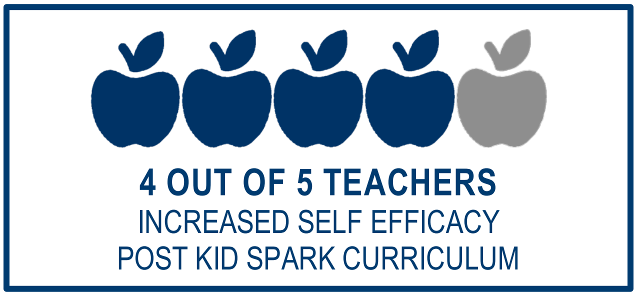
Vocabulary	Field Note Excerpt
Reinforce	TEACHER: We also built a bridge and we made things strong. Do you remember making it strong? BOY: The word was reinforce. TEACHER: Yes.
Gravity	*Teacher holds green block up and lets it go (it falls to floor).* TEACHER: What made it move? GIRL: Gravity.
Arch	GIRL *(to the other kids at her table)*: Look, if I put these two together I can connect them and make an arch.
Joints	TEACHER: What are the places called where the blue ones come together? A FEW KIDS: Joints.
Pyramid	TEACHER: What else did you learn? GIRL: There are six pyramids on top of the green block.
Cube	BOY: If you put two together it is the same as the yellow cube.

Impact on Teacher Learning

One of Kid Spark's primary goals is to increase teachers' self-confidence as STEM educators. Based on classroom observations, results from the Engineering Self Efficacy Teacher Survey, and teacher feedback, teachers' participation in designing and implementing the Kid Spark curriculum improved their <u>self-efficacy as an engineering educator</u> and <u>value for teaching engineering</u>. However, teachers still indicated a need for more knowledge of engineering content and more opportunities to teach engineering to young children.

<u>Self-Efficacy in Teaching Engineering</u>

Teachers' self-efficacy in teaching engineering was low at the start of the year (Mean=2.6 on a 5-point scale) but increased for four out of five of the teachers (Mean=3.1).



The following quotes from the final focus group illustrate both teachers' increased self-efficacy and their continued apprehension about the content area.

"If someone had told me I had to teach engineering, I would have said there's just no way, and I still don't think I was equipped to do that great a job, but I learned that I could get through it, I can do this, it will be okay, and they'll still learn something."

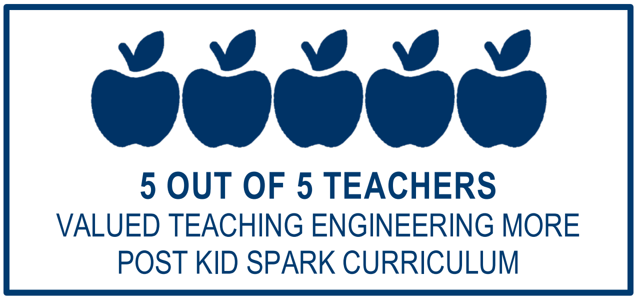
"Certain areas I feel more comfortable in, in terms of the vocabulary being used and more exposure to what engineers do, but I still think I need more practice in the hands-on things because when I look at the picture I can't quite see what's behind. Maybe I need one of those 3-D shots. More practice with that."

"There is always a feeling that I don't know if I'm covering it just right."

"If somebody had told me to teach engineering before I would have said I don't have curriculum, I don't have tools and I don't know what I am going to teach, but I definitely learned that it's not so hard if we have what we need."

"It's not scary anymore."

Value for Teaching Engineering
Teachers reported an increased value for teaching engineering to young children. After participating in Kid Spark, all five teachers felt it was more important to know how to teach engineering to young children. (On a 5-point scale, Pre Mean=2.6; Post Mean=3.8).

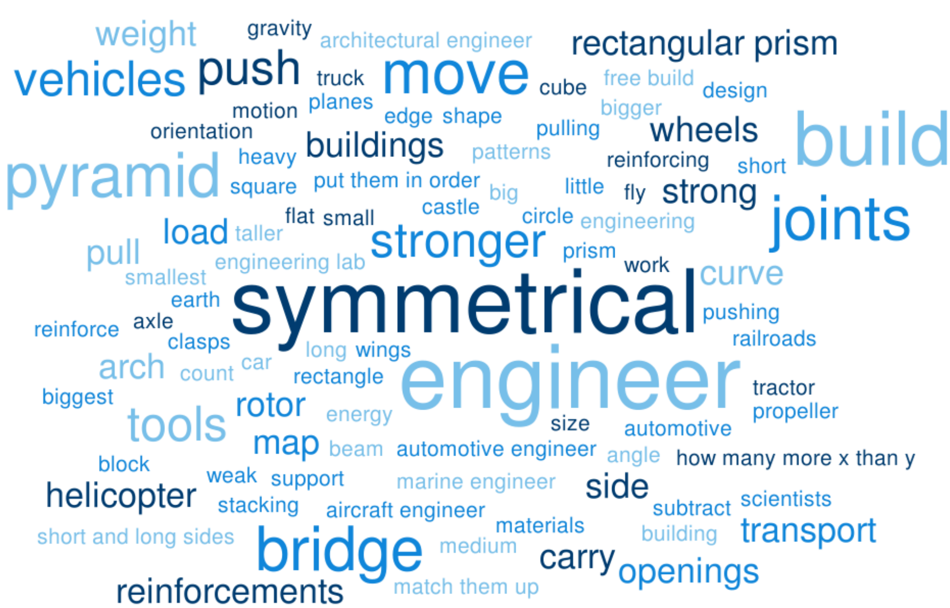


Infusing Engineering into Instruction

Although teachers expressed a lack of knowledge in engineering as a content area, classroom observations provided clear evidence that using the revised curriculum allowed teachers to introduce STEM vocabulary and engineering concepts through inquiry-based hands-on investigation. The observation protocols were designed to capture each time a teacher used STEM vocabulary during the lessons. Figure 5 depicts the number of vocabulary words teachers were heard using during 17 observations. The size of the word denotes the frequency of its use.

> *"I learned some terms like 'beam'. I knew that word but applying it to the bridge was new. 'Symmetrical' I used more in second grade but I liked that I could use the blocks to teach symmetry and that I could do this with other cubes too. I liked learning how to test it. Test and reinforce it. I liked that, too. Testing something and making it better."*
>
> – Teacher

Figure 5: Teachers' Use of STEM Vocabulary During 17 Kid Spark Lessons (n=5)



In addition to introducing STEM vocabulary, the revised lessons provided teachers opportunities to employ strong pedagogical practices such as asking open-ended questions and using both convergent (single solution) and divergent (multiple solutions) thinking. Although teachers still felt they had a lot to learn in order to become competent engineering educators, they felt their experience with Kid Spark was an important beginning. In fact, all participating teachers enthusiastically reported that they planned to do the curriculum again the following year, and that they felt they would be more prepared to enhance the lessons in the future.

LIMITATIONS

This study was exploratory in nature. The design-based research approach allowed for the enhancement of the PreK-1 curriculum, and the analysis of observational and teacher self-report data suggested that Kid Spark positively impacted students and teachers. However, there were some limitations.

- Although the classroom observations took place in five classrooms with over 100 students, they primarily focused on a single table of four students in one classroom. In future research, it would be important to expand the number of teachers and students included in the focused-observations.
- To truly measure the impact of Kid Spark, we recommend a quasi-experimental research design in which students who participate in Kid Spark are assessed on some key indicators and compared to a group of similar students who do not participate. There are few STEM assessments designed for young children, but the Lens on Science[18] preschool assessment shows promise as a tool for future Kid Spark research.

[18] Greenfield, D. B., & Penfield, R. (2013). Lens on science: development and validation of a computer-administered, adaptive, IRT-based assessment for preschool children. *Institute of Education Sciences Grant* R305A090502, http://ies.ed.gov/funding/grantsearch/details.asp?ID=805

CONCLUSIONS AND RECOMMENDATIONS

The curriculum presented in this study is the result of researchers, teachers, and Kid Spark staff partnering to design a program to meet the needs of young children who do not typically have access to engineering learning experiences. The findings from this report highlight the ways in which the revised PreK-1 curriculum impacted students' and teachers' development of a STEM identity. Students showed evidence of growth in building foundational STEM fluencies, engaging in science and engineering practices, and developing knowledge of the field of engineering. Teachers demonstrated increased self-efficacy and value for the teaching of engineering as well as increased knowledge in basic engineering concepts and practices.

Kid Spark's commitment to the ongoing refinement of their educational programs to best meet the needs of students and teachers is clearly evident in their support of this research study. In light of this commitment to ongoing improvement, adopting the following recommendations will likely lead to a stronger early childhood curriculum that can be adapted to fit a range of educational settings, both formal and informal.

- Utilize the revised curriculum's format and content to guide the final development of the PreK-1 curriculum. In further refinement of the units/lessons, prioritize instruction around the engineering concepts and then align building activities with the concepts.
- Develop training and support materials for teachers that include background information on engineering concepts and practical tips for using the blocks. Teachers preferred a handout for the content knowledge and a video or handout for the construction tips.
- Make minor revisions to the Kid Spark Mobile STEM Labs including re-designing figurines to represent greater gender and ethnic diversity, ensuring there are enough blocks to account for broken blocks and for each child to complete a build from a construction mat, and updating construction mats with high resolution images and step-by-step visual instructions.
- Continue to evaluate both the implementation and effectiveness of Kid Spark's programs. Consider conducting a large-scale evaluation using a quasi-experimental research design, in which there is a comparison group comprised of students and/or teachers who do not participate.

APPENDICES A-D

Please contact Dr. Tessa Tinkler at The Nonprofit Institute to request access to the appendices:

Appendix A: Methods of Analysis
Appendix B: Classroom Observation Coding Rubric
Appendix C: Photo Coding Rubric
Appendix D: Revised Curriculum